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Comparative toxicity of synthetic insecticides against *Anomala rugosa* (Coleoptera: Scarabaeidae: Rutelinae)

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Abstract
The efficacy of 21 insecticides was tested against *Anomala rugosa* under laboratory conditions in June-July, 2021. To evaluate the efficacy of insecticides, two methodologies *viz.*, leaf dip bioassay and contact toxicity bioassay were carried out. Overall, the tested species showed substantial variation in susceptibility to the tested chemical insecticides with mortality of beetles ranging from 0 to 100 %. Chlorpyriphos 20% EC @ 2 mL/L was proved to be the most potent insecticide in terms of toxicity. The tested species recorded percent mortality of 100.00±0.00 in treatment with chlorpyriphos at 24 HAT in both leaf dip as well as contact toxicity bioassay. The second most potent insecticide was Dichlorvos 76% EC @ 1 mL/L, it recorded percent mortality of 96.67±3.33 and 100.00±0.00 at 24 HAT and 48 HAT, respectively in leaf dip bioassay. In contact toxicity bioassay, it recorded percent mortality of 90.00±5.77 and 100.00±0.00 at 24 HAT and 48 HAT, respectively. Besides these, the treatment with Acephate 75% SP (90.00±5.77), Cypermethrin 25% EC @ 0.5 mL/L (60.00±10.00), Deltamethrin 2.8% EC @ 1 mL/L (53.33±3.33), Lambda-cyhalothrin 5% EC (90±5.77) and Malathion 50% EC @ 2 mL/L (83.33±3.33) provided high mortality of *Anomala rugosa* in leaf dip bioassays at 48 HAT. But, they did not yield a promising rate of efficacy in contact toxicity bioassay. The treatment with Acetamiprid 20% SP, Azadirachtin 0.15% EC, Buprofezin 25% SC, Cartap hydrochloride 50% SP, Chlorantraniliprole 18.5% SCL, Chlorfenapyr 10% SC, Cyantraniliprole 10.26% OD, Emamectin benzoate 5% SG, Fipronil 5% SC, Flubendiamide 39.35% SC, Imidacloprid 17.8% SL, Indoxacarb 14.5% SC, Metasystox 25% EC and Spinosad 45% SC did not report a promising rate of efficacy in both bioassays. Thus, our study created a species-specific and scientific base for scarab beetle (*Anomala rugosa*) management using efficacious insecticides.

Keywords: scarab beetles, white grubs, insecticides, leaf dip bioassay, contact toxicity bioassay

Introduction
Coleoptera is the most diverse and largest order of the class Insecta (Phylum: Arthropoda) (Bajad *et al.*, 2019) [1]. It includes about 3,50,000 species worldwide, of which about 15,088 species are known from the Indian sub-region (Parvez and Srivastava, 2010) [2]. The family Scarabaeidae Latreille, 1802 of the superfamily Scarabaeoidea is the second largest cosmopolitan family within the order Coleoptera (Bajad *et al.*, 2019) [1]. Scarabaeidae includes 33,504 species worldwide (Schoolmeesters, 2020) [3]. The family Scarabaeidae comprises of Pleurosticti and Laprosticti species (Naveena *et al.*, 2021) [4]. The Pleurosticti group includes the chafer species under the subfamily Cetoniinae, Dynastinae, Melolonthinae and Rutelinae. The Laprosticti group includes the dung beetles under the subfamily Aphodiinae and Scarabaeinae. Majority of scarab beetles belonging to the pleurostict group especially species belonging to the subfamily Melolonthinae and Rutelinae are recorded as notorious pests of various cultivated as well as uncultivated plants (Nutan *et al.*, 2022) [5]. They are pestiferous in both adult as well as larval stages. The larva are subterranean and voraciously feed on the roots of various plants while the adults are defoliators (Sushil *et al.*, 2022) [6]. Several researchers have reported that white grubs cause 20-100% damage (Devanda *et al.*, 2021[7]; Baloda *et al.*, 2021) [8] to various crops all over the world. Due to their polyphagous nature, white grubs have been identified as pest of national importance (Misra and Chandla, 1989) [9] and a major limiting factor of agricultural production (Sharma *et al.*, 2021) [10]. Moreover, the pleurostict scarab beetles feed on the flower, foliage and fruits leading to economic injury (Hammons *et al.*, 2008) [11]. The beetles skeletonize the leaves and consume fruits like apples, peaches and plums (PennState Extension, 2016 [12]; Althoff and Rice, 2022) [13]. The adults prefer early ripened or already damaged fruits (Pires and Koch, 2020) [14], but in pest outbreak conditions they can damage all the fruits (Hadley, 1940) [15]. Since 1888, researchers have made several attempts to control white grub species by using numerous control tactics (GC, 2006) [16] including cultural, mechanical, chemical, biological and integrated methods (Nutan *et al.*, 2022) [5] all over the world. Out of these, the chemical control tactics *i.e.*, the application of chemical pesticides is continued to be used as a sole option during pest outbreak conditions to avoid economic loss. As the gregarious scarab beetles emerge in large numbers and get aggregated on the host trees in pest outbreak conditions. They can be controlled if the host trees are treated with efficacious insecticides, without widespread chemical sprays and contamination. This management strategy not only decreases the damage done by pleurostict beetles to host

trees but indirectly reduces the egg-laying which in turn reduces the scarab population (Nutan *et al.*, 2022) [5]. The laboratory bioassay studies to find the most efficacious insecticide against predominant and notorious scarab beetles will help in their management under pest outbreak conditions. So, the present study was conducted to evaluate the efficacy of 21 chemical insecticides available in the local market against *Anomala rugosa* under laboratory conditions.

Material and Methods

The efficacy of 21 chemical insecticides available in the market (Table 1) was evaluated against *Anomala rugosa* at Entomology Laboratory, Experimental Farm, ICAR-VPKAS (29.63º N and 79.63º E, 1250 amsl), Almora, Uttarakhand. The bioassay study was carried out from June to July 2021 under laboratory conditions.

Collection of Scarab Beetles

The nocturnal chafer beetles (*Anomala rugosa*) were hand-picked from their preferred host trees (*Lagerstroemia indica*, *Ligustrum nepalensis* and *Rosa indica*) between 19:30 to 20:30 hours during *in situ* samplings of scarab beetles at Experimental Farm, Hawalbagh, Almora, Uttarakhand. They were transported to the laboratory in 1 L sterile plastic containers with fresh shoots of *Ligustrum nepalensis*. The collected adults were maintained overnight before treatment and kept in a separate mesh cage with a bucket of autoclaved soil and farm yard manure mixture (1:1). The adult beetles feed on the aerial parts of the plants. So, freshly cut shoots of *Ligustrum nepalensis* were pressed in the soil mixture. After 24 hours, actively moving healthy adults were selected and were used for the laboratory bioassay studies.

Bio-Efficacy Studies with Chemical Insecticides against Scarab Beetles

To investigate the efficacy of insecticides against *Anomala rugosa*, two methodologies *i.e.*, ingestion toxicity (leaf dip bioassay) and contact toxicity (filter paper contamination bioassay) were adapted as per Stanley and Preetha (2016) [17].

Leaf Dip Bioassay

The leaves from *Ligustrum nepalensis* were collected freshly and surface sterilized. The leaves were dipped in insecticide solutions at their recommended dosage for 60 seconds and allowed to shade dry. After shade drying, healthy adults were allowed to feed on the treated leaves in insect rearing boxes (9 cm diameter x 5 cm height) for 24 hours. A total of 10 adults were kept per box. A total of 30 adults were tested per treatment with three replications each, along with control-treated with water. After 24 hours, treated leaves along with leaf debris and excrements were removed from boxes. The fresh and uncontaminated leaves were added to the boxes. The mortality was recorded at 24 and 48 HAT and percent mortality was worked out by counting the number of healthy and dead adults in both treated and control boxes.

Contact Toxicity Bioassay

A 9 cm diameter Whatman no. 1 filter paper was impregnated with 1 mL solution of test concentration of selected insecticide and air-dried for 30 minutes. After air drying, the beetles were released onto the filter paper in a petri dish. After 4 hours of contact, the beetles were transferred to fresh insect rearing boxes (9 cm diameter x 5 cm height) with fresh *Ligustrum nepalensis* leaves. In addition to this, a control treatment (treated with water) was also kept. Each treatment was replicated thrice and a total of 30 adult beetles were released in each replication. The data on mortality was recorded at 24 and 48 HAT.

Table 1: Details of the insecticides used for bioassay, along with their commercial formulation and recommended field dosage.

Treatments	Common name and formulation	Chemical group	Trade name	Dose
T1	Acephate 75% SP	Organophosphates	Acemain	1.6 g/L
T2	Acetamiprid 20 % SP	Chlornicotinyl group	Nagarjuna ennova	0.3 g/L
T3	Azadirachtin 0.15% EC	Botanical	Vanguard	6 mL/L
T4	Buprofezin 25% SC	Thiadiazinone	Tata applaud	2 mL/L
T5	Cartap hydrochloride 50% SP	Nereis toxin	Dartiz	1g/L
T6	Chlorantraniliprole 18.5% SC	Diamide group	Coragen	0.3 mL/L
T7	Chlorfenapyr 10% SC	Pyrroles	Intrepid	0.3 mL/L
T8	Chlorpyriphos 20% EC	Organophosphates	Chlorguard	2 mL/L
T9	Cyantraniliprole 10.26% OD	Diamide group	DuPont benevia	1 mL/L
T10	Cypermethrin 25% EC	Synthetic pyrethroid	Challenger	0.5 mL/L
T11	Deltamethrin 2.8% EC	Synthetic pyrethroid	Decis	1 mL/L
T12	Dichlorvos 76% EC	Organophosphates	Nuvan	1 mL/L
T13	Emamectin benzoate 5% SG	Avermectin	Rilon	0.4 g/L
T14	Fipronil 5% SC	Phenylpyrazole	Regent	0.3 mL/L
T15	Flubendiamide 39.35% SC	Diamide group	Fame	0.3 mL/L
T16	Imidacloprid 17.8% SL	Chlornicotinyl group	Maharaja	0.3 mL/L

T17	Indoxacarb 14.5% SC	Oxadiazine	King Doxa	1 mL/L
T18	Lambda-cyhalothrin 5% EC	Synthetic pyrethroid	Deva Shakti	1 mL/L
T19	Malathion 50% EC	Organophosphates	Tusk	2 mL/L
T20	Metasystox 25% EC	Organophosphates	UPL	1 mL/L
T21	Spinosad 45% SC	Spinosyn	Conserve	0.5 mL/L
T22	Untreated control	Water	-	-

Results and Disscussion

In the present study, a total of 21 chemical insecticides were tested against *Anomala rugosa* (Coleoptera: Scarabaeidae: Rutelinae). Overall, the tested species showed substantial variation in susceptibility to the tested chemical insecticides with mortality of beetles ranging from 0 to 100 % (Table 2). Chlorpyriphos 20% EC @ 2 mL/L was proved to be the most potent insecticide in terms of toxicity. The tested species recorded percent mortality of 100.00±0.00 in treatment with chlorpyriphos at 24 HAT in both leaf dip as well as contact toxicity bioassay. Chlorpyriphos has been tested against several white grub species, *Adoretus emarginatus*, *Brahmina coriacea*, *Holotrichia consanguinea*, *Heteronychus lioderes*, *Holotrichia serrata*, *Heteronychus licas* & *Lepidiota mansueta* and recommended to control white grubs in India (Manjula and Sulochanamma, 2001; Anitha *et al*., 2005; Ahad *et al*., 2006; Sharma and Chandla, 2013; Rahama *et al*., 2014; Bhattacharyya *et al*., 2017; Patel *et al*., 2020) [13, 18, 19, 20, 21, 22, 23, 24]. Ahad *et al.* (2006) [20] reported chlorpyriphos (2 L/ha) as the most effective insecticide in terms of toxicity against *Heteronychus lioderes*. They reported that the plots protected with chlorpyriphos provided maximum gram yield. The efficacy of chlorpyriphos was tested against *Brahmina coriacea* grubs and its application in potato fields reduced tuber damage to 2% compared to 20% tuber damage in the untreated control (Sharma and Chandla, 2013) [21]. Bhattacharyya *et al.* (2017) [23] tested the efficacy of carbofuran, chlorpyriphos, clothianidin, emamectin benzoate, imidacloprid and thiamethoxam against *Lepidiota mansueta* (grubs) in the potato field. They reported that experimental plots treated with chlorpyriphos recorded the lowest tuber damage (3.11 and 2.74% both on a weight and number basis) as well as the least number of grubs. The results of the bioassay studies corroborate with the findings of Manjula and Sulochanamma (2001) [18], Anitha *et al*. (2005)[19], Patial and Bhagat (2005) [25], Ahad *et al.* (2006) [20], Sharma and Chandla (2013) [21], Rahama *et al.* (2014)[22], Bhattacharyya *et al*. (2017) [23] and Nutan *et al.*, 2022 [5] reporting chlorpyriphos as the most potent chemical insecticide against insect pests.

The second most potent insecticide was Dichlorvos 76% EC @ 1 mL/L in terms of toxicity. The treatment with dichlorvos recorded percent mortality of 96.67±3.33 and 100.00±0.00 at 24 HAT and 48 HAT, respectively in leaf dip bioassay. In contact toxicity bioassay, it recorded percent mortality of 90.00±5.77 and 100.00±0.00 at 24 HAT and 48 HAT, respectively. Besides these, the treatment with Acephate 75% SP @ 1.6 g/L recorded percent mortality of 90.00±5.77 at 48 HAT in leaf dip bioassay. However, in contact toxicity bioassay, the treatment with acephate recorded percent mortality of 23.33±3.33 at 48 HAT. Acephate is reported to be effective in controlling sucking and biting insects by direct contact or ingestion (Tomlin, 2009) [26]. Wu *et al.* (2021) [27] also reported acephate as an effective treatment against *Spodoptera frugiperda* in the field in China. They reported 91.18% control of *Spodoptera frugiperda* through root irrigation of acephate @ 6000 g/ha.

Cypermethrin and lambda-cyhalothrin are broad-spectrum synthetic pyrethroids that have been widely used since the 1980s to control several insect pests in agricultural as well as horticultural crops (Willoughby *et al*., 2020) [28]. Cypermethrin 25% EC @ 0.5 mL/L recorded percent mortality of 53.33±8.82 and 60.00±10.00 at 24 HAT and 48 HAT, respectively in leaf dip bioassay. In contact toxicity bioassay, cypermethrin recorded percent mortality of 23.33±3.33 at 48 HAT. The treatment with Lambda-cyhalothrin 5% EC @ 1 mL/L provided promising results with percent mortality of 90±5.77 at 48 HAT in leaf dip bioassay. But, it has not provided promising rates of efficacy in contact toxicity bioassay as it recorded percent mortality of 23.33±14.53 at 48 HAT. Martínez *et al.* (2014) [29] also reported lambda-cyhalothrin to be effective insecticides with $LC_{50\text{-}90}$ value *i.e.*, χ^2= 42.52 against *Strategus aloeus* (adults).

Acetamiprid and imidacloprid are known to affect or kill insects by direct contact or ingestion (Willoughby *et al*., 2020)[28]. They have been used widely since the 1990s to control several insect pests. The treatment with Acetamiprid 20% SP @ 0.3 g/L and Imidacloprid 17.8% SL @ 0.3 mL/L recorded percent mortality of 23.33±3.33 and 23.33±6.67, respectively at 48 HAT in leaf dip bioassay. However, in contact toxicity bioassay, the treatment with acetamiprid and imidacloprid recorded percent mortality less than equal to 10.00±5.77. Willoughby *et al*. (2020) [28] and Moore *et al.* (2021) [30] reported acetamiprid as an effective insecticide for controlling *Hylobius abietis*. Imidacloprid has been proved to be an effective insecticide to control several white grub species, *Brahmina coriacea*, *Cyclocephala borealis, Holotrichia consanguinea*, *Holotrichia reynaudi*, *Holotrichia serrata*, *Leucopholis lepidophora and Popillia japonica* (Grewal *et al.*, 2001; Anitha *et al.*, 2005; Adarsha *et al.*, 2015) [31, 19, 32]. The application of imidacloprid reduced 88.88% to 100% grubs of *Leucopholis lepidophora* in areca nut plantations in Karnataka, India (Adarsha *et al.*, 2015) [32]. Although, the efficacy of acetamiprid and imidacloprid against insect pests is well documented but the results obtained from the present study showed contrasting observations with these findings.

The treatment with Malathion 50% EC @ 2 mL/L provided percent mortality of 83.33±3.33 at 48 HAT in leaf dip bioassay. Although, it does not provide a promising rate of efficacy in contact toxicity bioassay as the treatment with malathion recorded only 16.67±6.67 percent mortality at 48 HAT.

For several decades, azadirachtin has been used for plant protection in agriculture, horticulture and forests (Benelli *et al.*, 2017) [33]. It has been reported to be effective against several pleurostict insect pests through multiple modes of action including mating disruption (Copping, 2009) [34]. But, in the present study, Azadirachtin 0.15% EC @ 6 mL/L was found to be ineffective against *Anomala rugosa* as no mortality was recorded in treatment with azadirachtin in both bioassays. Sivparsad *et al*. (2020) [35] also reported azadirachtin to be the least effective treatment against white grub species, *Schizonycha affinis* in pot trials in South Africa.

Although chlorantraniliprole is a non-neonicotinoid synthetic insecticide with relatively low mammalian toxicity (Macbean, 2012) [36], it affects or kills insects by direct contact or ingestion (Willoughby *et al*. 2020) [28]. It is reported to cause death in a range of agricultural and horticultural pests including Lepidoptera and some Coleoptera, Diptera and Isoptera species (Macbean, 2012) [36]. But, Chlorantraniliprole 18.5% SC @ 0.3 mL/L has not provided promising rates of efficacy in both leaf dip as well as contact toxicity bioassay studies against *Anomala rugosa*. The treatment with chlorantraniliprole recorded percent mortality of less than equal to 3.33±3.33 in both bioassays at 48 HAT. Rana *et al.* (2021) [38] reported 56.67% mortality of *Melolontha indica* grubs with the treatment with chlorantraniliprole. Although, chlorantraniliprole was reported as an effective insecticide against the grubs of *Brahmina coriacea*, *Leucopholis lepidophora* and *Melolontha indica* (Adarsha *et al.*, 2015; Koranga *et al.*, 2020; Willoughby *et al.*, 2020; Moore *et al.*, 2021; Rana *et al.*, 2021) [32, 37, 28, 30, 38] but the results of the present study showed contrasting observations with these findings.

Chlorfenapyr 10% SC @ 0.3 mL/L recorded percent mortality of 30.00±5.77 and 6.67±3.33 in leaf dip and contact toxicity bioassay, respectively at 48 HAT. The toxicity by direct contact and ingestion has been reported in *Spodoptera exigua* and *Anopheles gambiae* (N'Guessan *et al*., 2007; Zhang *et al*., 2009) [41, 42]. Zhao *et al.* (2018) [43] also reported that larvae of *Bradysia odoriphaga* were susceptible to chlorfenapyr and recorded LC_{50} at 9.882 mg/L in bioassay under laboratory conditions in China. Although, chlorfenapyr is currently registered for the control of several insect pests (Rand, 2004; Ullah *et al.,* 2016) [39, 40] but it has not provided a promising rate of efficacy in the present bioassay study.

The treatment with Deltamethrin 2.8% EC @ 1 mL/L provided percent mortality of 53.33±3.33 at 48 HAT in leaf dip bioassay. But, it does not provide a promising rate of efficacy at 48 HAT in contact toxicity bioassay. Sivparsad *et al.* (2020) [35] tested the efficacy of 14 insecticides including deltamethrin against *Schizonycha affinis* in pot trials in South Africa. They also reported deltamethrin as a less promising insecticide in terms of toxicity in controlling white grubs.

Emamectin benzoate 5% SG @ 0.4 g/L was proved to be ineffective, as the treatment with emamectin benzoate recorded no mortality even after 48 HAT in both contact toxicity and leaf dip bioassay studies. Adarsha *et al.* (2015) [32] and Bhattacharyya *et al*. (2017) [23] also reported emamectin benzoate as the least effective insecticide against *Leucopholis lepidophora* and *Lepidiota mansueta.*

Fipronil 5% SC @ 0.3 mL/L does not provide a promising rate of efficacy *i.e.,* recorded percent mortality less than equal to 10.00±5.77 at 48 HAT in both bioassays. Martínez *et al.* (2014) [29] reported fipronil to be an effective insecticide with LC_{50-90} value *i.e.,* $\chi 2$= 37.81 against *Strategus aloeus* (adults). Although, the efficacy of fipronil against white grubs is well documented (Bhattacharyya *et al.*, 2015; Pujari *et al.*, 2017) [44, 45] but our study does not show similarity with other findings which successfully utilized fipronil as potent insecticides against white grubs.

Spinosad is reported to control several insect pests including pleurostict beetles (Willoughby *et al*., 2020) [28]. The treatment with Spinosad 45% SC @ 0.5 mL/L recorded percent mortality less than equal to 6.67±3.33 in both leaf dip as well as contact toxicity bioassay against the tested scarab beetle. Martínez *et al.* (2014) [29] also reported spinosad as the least effective treatment with LC_{50-90} value *i.e.*, $\chi 2$= 12.02 against *Strategus aloeus* (adults). Moreover, the treatment with Buprofezin 25% SC @ 2 mL/L, Cartap hydrochloride 50% SP @ 1g/L, Cyantraniliprole 10.26% OD @ 1 mL/L, Flubendiamide 39.35% SC @ 0.3 mL/L, Indoxacarb 14.5% SC @ 1 mL/L and Metasystox 25% EC @ 1 mL/L does not provided a promising rate of efficacy in both leaf dip as well as contact toxicity bioassay. Although Acephate 75% SP, Lambda-cyhalothrin 5% EC and Malathion 50% EC provided high mortality of *Anomala rugosa* in leaf dip bioassays but they are not proved to be effective in direct contact toxicity bioassays. It may be attributed to several causes including insufficient dose, insufficient time for mortality to become apparent, the difference in the mode of action or they must be ingested to cause mortality.

Table 2: Evaluation of chemical insecticides against adults of *Anomala rugosa* under laboratory conditions.

Treatments	Leaf dip bioassay		Contact toxicity bioassay	
	24 HAT	48 HAT	24 HAT	48 HAT
T1	56.67±8.82	90±5.77	3.33±3.33	23.33±3.33
T2	16.67±3.33	23.33±3.33	3.33±3.33	10.00±5.77
T3	0	0	0	0
T4	0	3.33±3.33	0	0
T5	3.33±3.33	10.00±5.77	0	0
T6	0	3.33±3.33	0	0
T7	16.67±8.82	30.00±5.77	3.33±3.33	6.67±3.33
T8	100.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00
T9	0	13.33±3.33	0	0

T10	53.33±8.82	60.00±10.00	10.00±5.77	23.33±3.33
T11	30.00±5.77	53.33±3.33	3.33±3.33	10.00±5.77
T12	96.67±3.33	100.00±0.00	90.00±5.77	100.00±0.00
T13	0	0	0	0
T14	3.33±3.33	10.00±5.77	0	3.33±3.33
T15	16.67±6.67	16.67±6.67	0	0
T16	10.00±5.77	23.33±6.67	0	3.33±3.33
T17	10.00±5.77	10.00±5.77	0	0
T18	66.67±8.82	90.00±5.77	10.00±10.00	23.33±14.53
T19	60.00±5.77	83.33±3.33	0	16.67±6.67
T20	16.67±6.67	30.00±5.77	0	3.33±3.33
T21	0	6.67±3.33	0	0
T22	0	0	0	0
SE (m)	5.202	4.772	3.121	4.155
CV (%)	35.606	24.033	53.249	48.973
F value	38.003	57.027	78.6	48.085
P value	0.000020	0.000013	0.000009	0.000017

Many researchers have reported that white grub species such as *Macrodactylus subspinosus*, *Oryctes rhinoceros* and *Popillia japonica* were susceptible to the different concentrations of insecticides (Isaacs *et al.*, 2004; Baumler and Potter, 2014; Sreeletha and Geetha, 2012) [46, 47, 48]. So, further studies are needed to test different concentrations of efficacious chemical insecticides against notorious white grub species. In addition to this, the combination of potent insecticides with entomopathogens for high pathogenicity to adults and grubs of common and notorious white grub species needs to be investigated. The compatibility of insecticide with entomopathogen is to be investigated before experiments with white grubs. Nagal *et al.* (2021) [49] tested the efficacies of seven insecticides against *Holotrichia consanguinea* (adults) through an adult vial test. They reported bifenthrin 10 EC as the most potent insecticide followed by fipronil + imidacloprid 80 WG, clothianidin 50 WDG, imidacloprid 17.8 SL, fipronil 80 WG, imidacloprid 600 FS and quinalphos 25 EC with LC_{50} values 0.08, 0.20, 0.76, 0.77, 1.44, 1.53 and 36.58 ppm, respectively. A combination of imidacloprid and fipronil was also found to be the most effective treatment for the control of white grub followed by clothianidin, flubendiamide and rynaxypyr (Mane and Mohite, 2014) [50].

The majority of the previous studies focused on evaluating the effectiveness of chemical insecticides against the grubs and rarely focused on the scarab beetles (Manjula and Sulochanamma, 2001; Sharma and Chandla, 2013; Adarsha *et al*., 2015; Bhattacharyya *et al*., 2017; Koranga *et al*., 2020; Rana *et al*., 2021) [18, 21, 32, 23, 37, 38]. The chemical control tactics can be adapted for the management of scarab beetles (Martinez *et al*., 2014; Nagal *et al.*, 2021; Nutan *et al*., 2022) [29, 49, 5] because of the quick action of efficacious chemical insecticides. Although foliar spray of insecticides on host trees is recommended for the management of scarab beetles but, no scientific information is clearly available regarding the selection of suitable and efficacious insecticides for the management of *Anomala rugosa*. So, our study was focused to create a species-specific and scientific base for *Anomala rugosa* management using efficacious insecticide.

Conclusion

Chlorpyriphos 20% EC @ 2 mL/L was the most effective followed by Dichlorvos 76% EC @ 1 mL/L against *Anomala rugosa* (Coleoptera: Scarabaeidae: Rutelinae). The commonly recommended concentration of these two insecticides provided maximum mortality in both leaf dip as well as contact toxicity bioassay in comparison with the other tested chemical insecticides. Besides these, other insecticides *viz.,* Acephate 75% SP, Lambda-cyhalothrin 5% EC and Malathion 50% EC performed well recording mortality ranging between 80-90%, they might be lethal to other species also. Given this, further studies to screen out the combination of potent insecticides with entomopathogens against notorious white grub species which may provide a powerful and economically feasible curative control for white grub management need to be investigated.

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